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Implementation of Dredging Risk Assessment Modeling Applications for Evaluation of the No-Action Scenario and Dredging Impacts

PURPOSE: This technical note describes the development of Dredging Risk Assessment Modeling Applications (DRAMA) for evaluation of the no-action scenario and the impacts of dredging operations without consideration of disposal. Implementation templates for these scenarios use existing dredging models to characterize exposure for the evaluation of potential human health and ecological risk. The models selected have been incorporated into the Framework for Risk Analysis in Multimedia Environmental Systems (FRAMES), a part of the Army Risk Assessment Modeling System (ARAMS).

BACKGROUND: The risk assessment paradigm (Figure 1) is typically a problem formulation leading to both exposure and effects assessments, which are integrated to perform a risk characterization (Moore et al. 1998). The basic premise is to calculate risk as a function of both exposure, human or ecological, and effects resulting from exposure. The effects of concern may result from short- or long-term exposures. The risk assessment techniques for the evaluation of dredging activities require exposure effects data and/or predictions generated by models. Exposure models are required to predict exposures resulting from proposed alternatives where exposure data do not exist. The combination of the exposure and effect components results in a calculated risk characterization. Risk assessments are useful planning tools for the evaluation and determination of the impact of dredging and disposal alternatives on both human and ecological resources (Moore et al. 1998).

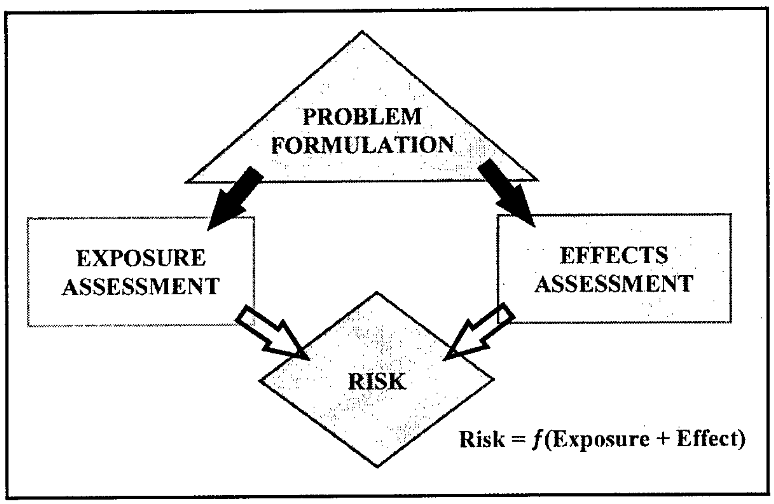


Figure 1. U.S. Environmental Protection Agency risk assessment paradigm

Historically, there have been several options for conducting risk assessments. Perhaps the simplest of these involves direct field measurements to estimate exposure concentrations for a given exposure scenario. These direct exposure estimates are then compared to effects data to estimate a risk, e.g., a hazard quotient (U.S. Environmental Protection Agency (USEPA) 1992). One problem with this method is the assumption that the exposure concentrations collected at the sample sites are temporally constant. In addition, the spatial distribution of the exposure concentrations is generally limited due to the expense of field measurements. To gain an understanding of the influence of time and spatial variances upon the estimated exposure concentration (for a given exposure scenario),

an exposure assessment model should be used. The exposure assessment can use screening level models that employ simplifying, conservative assumptions to reduce the complexity, data requirements, modeling effort, time requirements, and costs. Screening level risk assessment is appropriate for comparative risk assessment or when a lower level of precision, resolution, and accuracy is needed. Comprehensive models are more physically based, both spatially and temporally, than the screening level models and typically require increased data and computing resources.

Comparative risk assessment is a methodology that uses sound science, policy, economic analysis, and stakeholder participation to identify and address the areas of greatest environmental risks and provide a framework for prioritizing environmental problems. Comparative risk assessment can be used to determine the relative risks of environmental hazards by a systematic, documented process that provides technical information to decision-makers. The comparative risk process should be viewed as a whole, from collecting data, analyzing data, and ranking risk to developing an action plan and implementing new strategies for reducing risk. The results of a comparative risk analysis can be used to provide a technical basis for targeting activities, management priorities, and resources when there are not enough resources available to address all the environmental needs of a community.

The baseline condition in a comparative risk assessment for dredging operations is the no-action scenario, which represents the present and future risk posed by a contaminated sediment and water body without performing dredging. Dredging operations alter the short-term and long-term risks. When the risks of dredging operations are compared with the risks of the no-action scenario, the relative risk of dredging operations and changes in short- and long-term risk can be determined. Comparison of the no-action scenario with dredging in the absence of disposal of dredged material and discharge of dredging effluents to the water body provides comparative risk assessment for the aquatic environment.

PROBLEM: Environmental risk assessment can be a complex process requiring multidisciplinary expertise. To facilitate initial screening level assessments, PC-based risk assessment decision support tools have been and are being developed and applied to numerous land sites for estimating both human and ecological risks from exposures to hazardous and radioactive wastes. While these decision support tools have proven successful in providing site-specific risk estimates for human health and potential ecological impacts at Superfund sites, they have not been adapted for use in evaluating the potential impacts of navigation dredging operations. Numerous tools and protocols as presented in the Automated Dredging and Disposal Alternatives Modeling System (ADDAMS) (Schroeder and Palermo 1995) and the U.S. Army Corps of Engineers (USACE)/USEPA technical framework document (1992) have been developed to evaluate contaminant pathways at dredging operations. These dredging-related tools must be incorporated into a comprehensive risk assessment modeling system that provides linkages among fate models and toxicity databases to facilitate risk assessment in a manner consistent with the USACE/USEPA Technical Framework for Evaluating Environmental Effects of Dredged Material Management Alternatives.

OBJECTIVE: The objective of this research was to develop a PC-based, risk assessment decision support tool for evaluating the effects of dredging and disposal operations on human and ecological resources through modification of existing technology. Risk assessment scenarios (conceptual models and templates of model selection and integration with databases and assessment tools) were

to be built within ARAMS for common dredging and disposal operations to facilitate rapid application of the risk assessment system.

INTRODUCTION: To accomplish this objective several existing support programs and databases were integrated in FRAMES under ARAMS (Dortch 2001). ARAMS/FRAMES contained tools for conducting human health and ecological risk assessment, including the Multimedia Environmental Pollution Assessment System (MEPAS) for conducting human health risk, the Wildlife Ecological and Assessment Program (WEAP) for conducting ecological risk, and a database containing chemical-specific parameters required for fate/transport, uptake, and human health effects as defined by Health Effects Assessment Summary Tables (HEAST) and Integrated Risk Information System (IRIS). The ADDAMS programs for computing aquatic exposure concentrations, RECOVERY, DREDGE, and Thermodynamic Bioaccumulation Potential (TBP), and the databases for aquatic ecological effects, Environmental Residue Effects Database (ERED) and Biota Sediment Accumulation Factor (BSAF), were added to ARAMS/FRAMES for the evaluation of no-action and dredging impacts.

Figure 2 shows an example of the FRAMES Conceptual Site Model (CSM) interface where the user formulates the problem (builds a conceptual model for assessing the risk). In the conceptual model the user selects chemical properties, exposure and uptake parameters, receptors, and effects data, which are linked with various models. The user then chooses a source model and links it with fate and transport models to compute exposure and uptake. The exposure and uptake models are linked with effects assessment and risk characterization models. FRAMES contains the compartmented MEPAS model.

The implementation of the tools and the development of the no-action and dredging scenarios using RECOVERY, TBP, BSAF, DREDGE, and ERED are explained in greater detail in the following section.

MODULES FOR DREDGING AND NO-ACTION SCENARIOS

RECOVERY. RECOVERY is a PC-based screening-level model to assess the impact of contaminated bottom sediments on surface waters. RECOVERY was developed for modeling hydrophobic organic contaminants with a well-mixed water column, but it has been successfully applied to sites with a variety of contaminants. Contaminants are assumed to follow linear, reversible, equilibrium sorption and first-order decay kinetics. RECOVERY generates long-term time series of the concentration profile of contaminants in the sediment and the water column as well as the theoretical bioaccumulation potential for organisms. These concentrations provide the exposure predictions for use in risk characterization.

The RECOVERY model incorporated in ARAMS is an extension of versions developed and modified previously (Ruiz and Gerald 2001; Boyer et al. 1994). As shown in Figure 3, the system is idealized as a well-mixed surface water layer underlain by a vertically stratified sediment column. The sediment is uniform horizontally but segmented vertically into a well-mixed surface layer and deep sediment. The latter, in turn, is segmented into layers of user-defined thicknesses, properties, and contaminant concentrations underlain by a clean region. The discretized sediment layer configuration is useful for modeling capping projects and sites where contamination occurred over

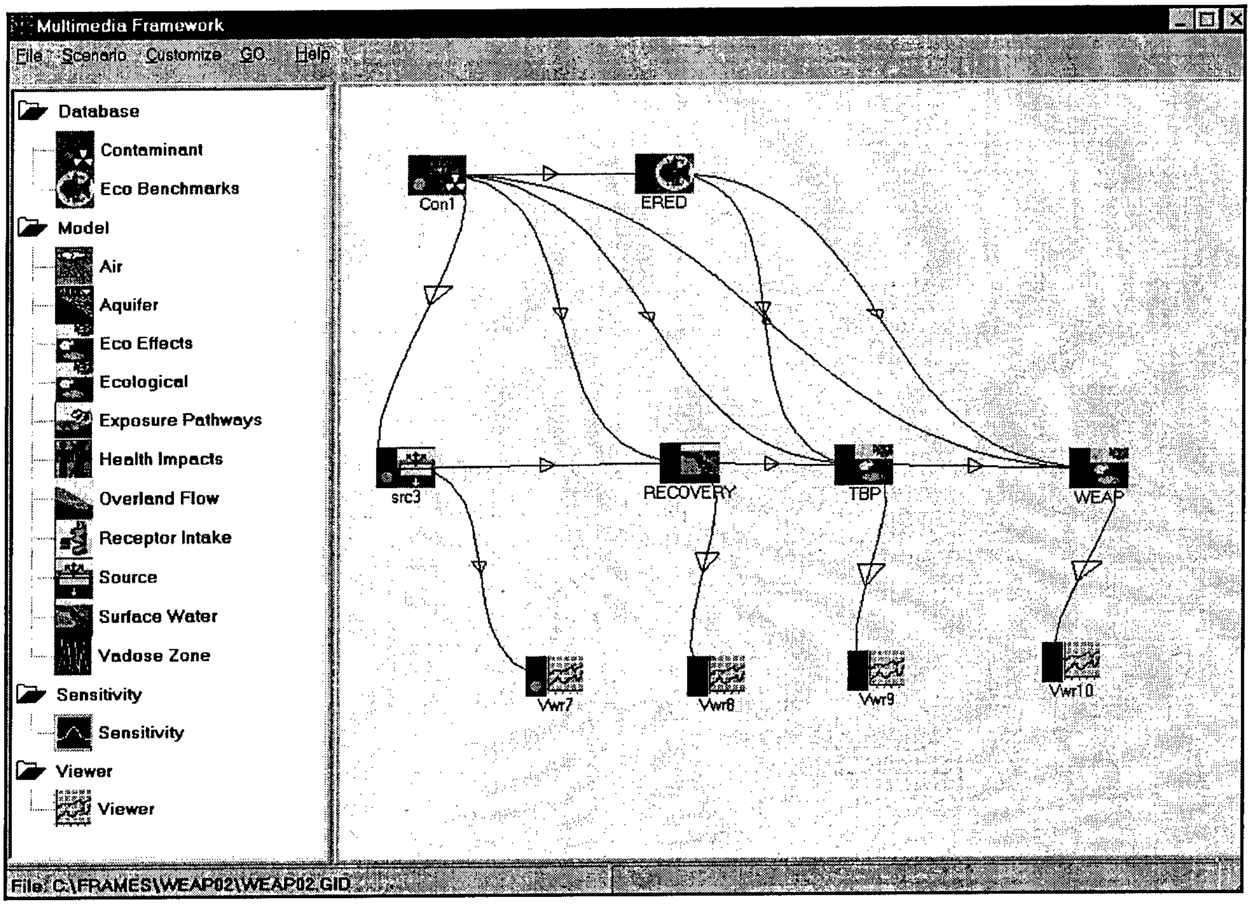


Figure 2. Schematic of the FRAMES conceptual site model

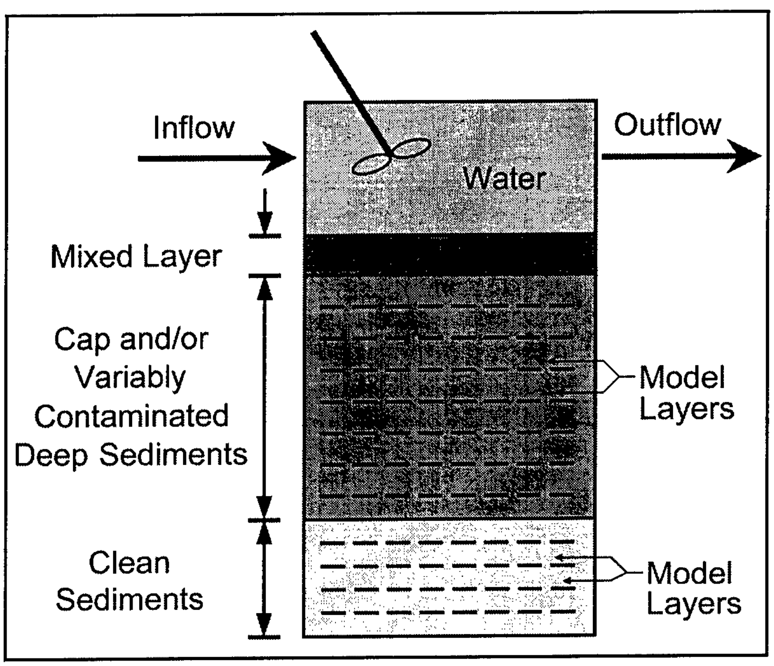


Figure 3. Physical configuration of RECOVERY

a long time, creating layers of varying contamination. The specification of a mixed surface layer is included because an unconsolidated layer is often observed at the surface of sediments due to a number of processes, including currents, bioturbation, and mechanical mixing.

Processes incorporated in RECOVERY are volatilization, sorption, decay, burial, resuspension, settling, advection, and pore-water diffusion. RECOVERY accounts for bioturbation with a completely mixed layer where the concentration is uniform with depth and an enhanced molecular diffusion zone to mimic bore tube pumping. Figure 4 shows the processes included in RECOVERY. The model can account for loads associated with point discharges, atmospheric loadings, and inflow.

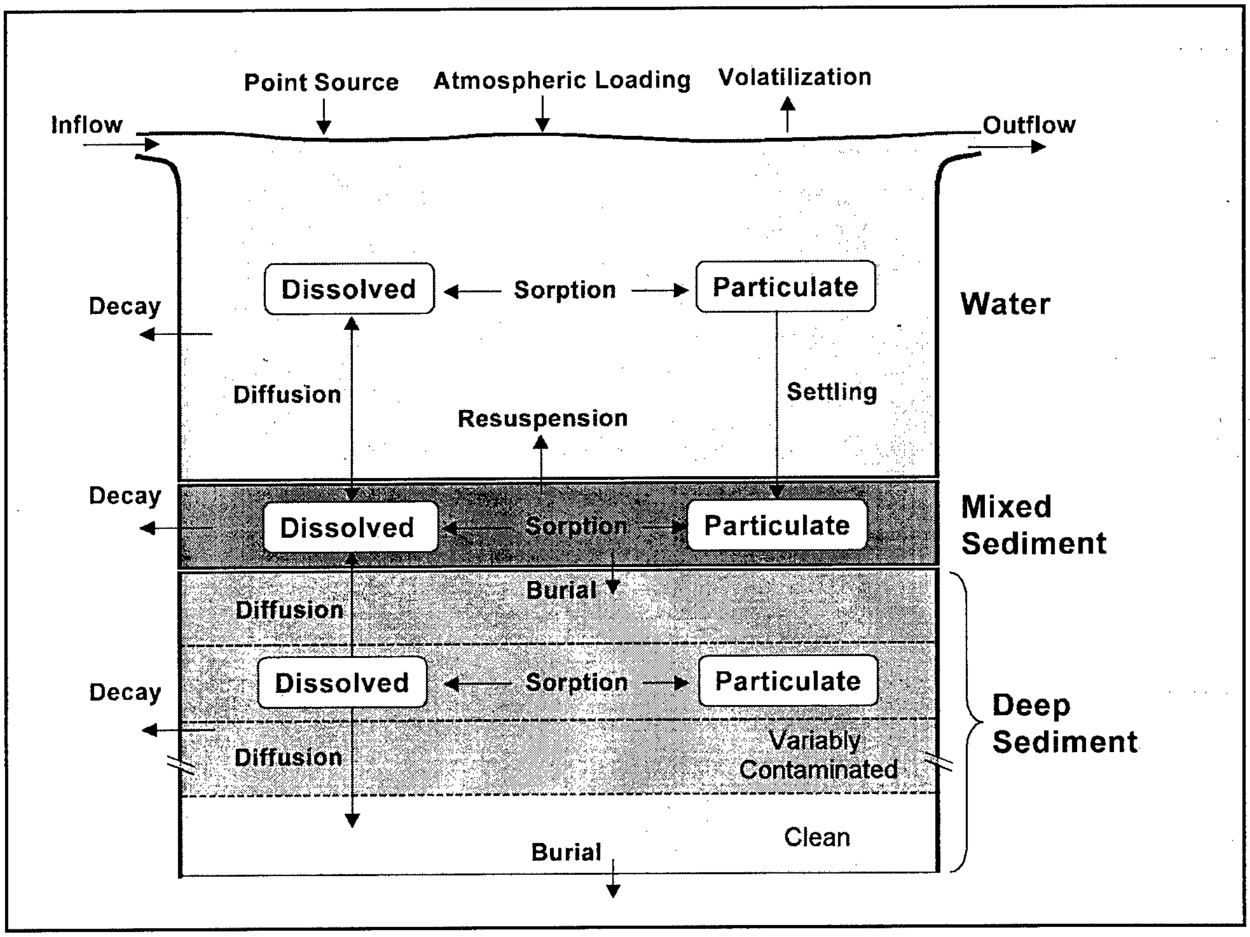


Figure 4. Schematic of RECOVERY processes

TBP: Theoretical Bioaccumulation Potential (TBP), an equilibrium partitioning-based screening model, is commonly used to evaluate dredged sediments for open-water disposal. The TBP model estimates the steady-state concentration of a neutral organic chemical that would ultimately accumulate in an organism from continuous exposure to contaminated sediment. TBP is calculated from chemical concentration and organic carbon content of the sediment, lipid content of the target organism, and the relative affinity of the chemical for sediment organic carbon and animal lipid (Figure 5). TBP is an estimate of the maximum bioaccumulation of contaminants in aquatic organisms. Bioaccumulation is a measure used to predict exposure effects for characterizing ecological risk.

The assumptions of the TBP model derive from thermodynamics. The system, consisting of sediment, organism, and water, is modeled as being closed. A neutral organic chemical in the system is given free movement and will distribute throughout the phases until equilibrium is established. The concentrations at equilibrium are determined by the chemical potentials in each phase. Organic carbon in the sediment and lipids in the organism are assumed to be the primary compartments that account for partitioning of neutral chemicals. Thus, the expected equilibrium concentration in an exposed organism of a given lipid content is a function of the concentration of a chemical in the sediment (normalized on the basis of its organic carbon content) and a partitioning coefficient between the sediment and the lipids (McFarland 1984; McFarland and Clarke 1987). The model equation is

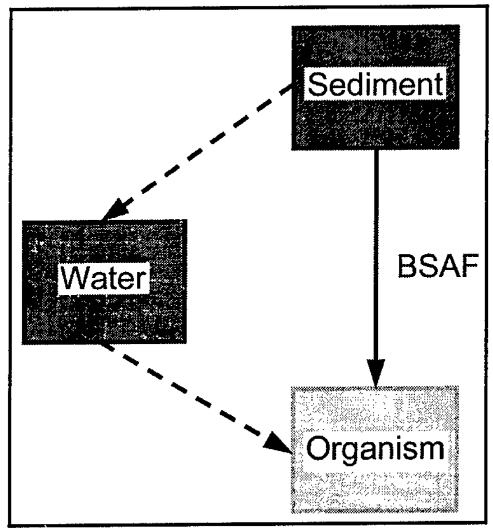


Figure 5. Schematic of TBP process

$$\text{TBP} = \text{BSAF}\,(C_s/f_{oc})\,f_L \qquad (1)$$

where the partitioning coefficient is the BSAF and

C_s = concentration of neutral organic chemical in sediment

f_{oc} = decimal fraction total organic carbon content of the sediment

f_L = decimal fraction lipid content of the target organism

TBP was incorporated into the RECOVERY model to assess the effect of contaminated sediments on biota (Ruiz and Gerald 2001). The model uses the organic carbon f_{oc} of the sediments and the estimated contaminant sediment concentration C_s to estimate the body burden of biota exposed to contaminated sediments over a long period of time (years or decades). The user is encouraged to use site-specific data to estimate BSAFs and biota lipid content. If site-specific data are not available, the BSAF database has lipid and BSAFs for a number of contaminants.

BSAF. The BSAF database was constructed from numerous field and laboratory observations. Empirically derived BSAFs were calculated as

$$\text{BSAF} = (C_t/f_L)\,/\,(C_s/f_{oc}) \qquad (2)$$

where C_t/f_L is the lipid-normalized contaminant concentration in the tissues of the exposed organism and C_s/f_{oc} is the organic carbon-normalized contaminant concentration in the sediment to which the organism has been exposed. The database contains BSAFs for contaminants of concern and lipid fractions for a number of organisms.

DREDGE. DREDGE uses empirical and analytical models to estimate the resuspension and transport of sediments and associated contaminants during dredging operations. DREDGE combines empirical sediment resuspension (near-field) models and simple suspended sediment transport

(far-field) models to estimate suspended sediment concentrations at specified water column locations. It then uses a linear equilibrium partitioning model to convert initial contaminant concentrations on in situ sediment and downstream suspended sediment concentrations to downstream water column particulate and dissolved contaminant concentrations. All calculations made by DREDGE assume steady-state time-invariant conditions. DREDGE predicts the short-term contaminant concentration distribution in the water column for determination of the acute effects from exposure to dredging and the spatial extent of the acute effects.

DREDGE uses empirical formulations developed from field studies to estimate the rate of sediment resuspension that results from a dredging operation (near-field source strength). DREDGE allows user-selected source strength values to be entered for any dredge type. Additionally, correlation models for source strengths are available only for cutterhead and bucket dredges. A number of limitations are associated with the models used in DREDGE. The sediment resuspension models are applicable only to dredging operations similar to those used in the development of the empirical equations. The models generally produce reasonable estimates for normal operating characteristics, but unusual operating parameters may yield unreasonable results.

The far-field transport models used assume a dominant, unidirectional current that exists sufficiently long for suspended sediment concentrations to reach steady state, assuming a steady source from a specific location and settling by Stokes' law. Although the dredge is moving continuously, the movement is usually slow compared to transport in the water column. Transport models solved analytically for plume geometries characteristic of cutterhead and bucket dredges are used to estimate downstream (far-field) transport of suspended sediments under steady-state conditions. Considerable simplifications are necessary to solve the fundamental transport equation analytically. While these simplifications limit the applicability of the resulting models, the analytical solutions allow for rapid calculation of suspended sediment concentrations with an accuracy compatible with the source strength models.

ERED. The USACE/USEPA ERED is a compilation of data taken from the literature where biological effects (e.g., reduced survival, growth, etc.) and tissue contaminant concentrations were simultaneously measured in the organism. Currently, the Web-based database is limited to those instances where biological effects observed in an organism are linked to a specific contaminant within its tissues (Bridges and Lutz 1999).

Currently, the system contains data from 736 studies published between 1964 and 2000. From these studies 3,463 distinct observations have been included online. The ERED includes data on 222 contaminants, 188 species, 13 effect classes, and 126 end points. Updates to the central database will occur periodically as new data sources and citations are discovered. Most papers involving mixtures of contaminants were excluded from the database because these effects could not be linked to a specific contaminant.

SCENARIO IMPLEMENTATION: The development of template dredging scenarios for the evaluation of both dredging and no-action alternatives in ARAMS provides the user a starting point for conducting a risk assessment. Implementation templates for these scenarios use existing dredging models to characterize exposure for the evaluation of potential human health and ecological risk. The exposure characterization in the scenarios is analogous to that currently

implemented under the ADDAMS toolkit. The user may elect to modify these templates to meet site-specific needs. Potential changes to the templates could include changes in pathways (uptake routes), source concentrations, and receptors (Figure 6).

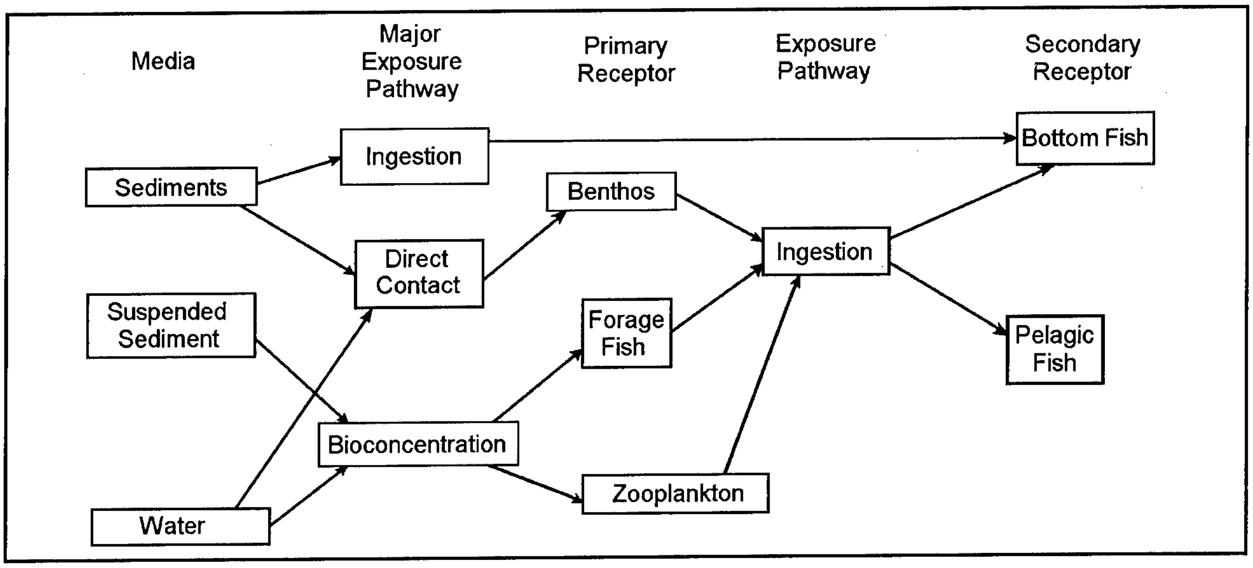


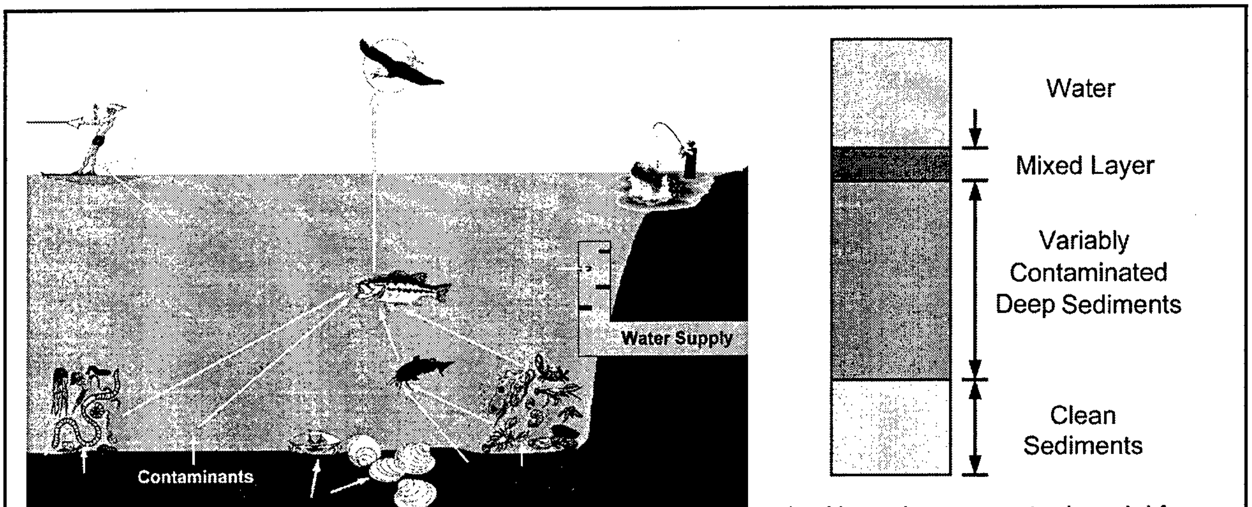
Figure 6. Risk assessment pathways

The scenarios represent generic conceptual models. In this manner, they include the typical sources, processes, and receptors addressed under no-action and dredging scenarios. The tools utilized for the scenarios allow the user to estimate exposure concentrations, uptake, and effects for the major pathways and receptors. However, the user can select other tools and receptors to address site-specific needs. Both human and ecological risk end points have been included in the scenarios.

The generic scenarios for no-action and dredging impacts are provided as read-only files. Users of the system will be required to save their site-specific application under a unique file name. This feature aids the user by not having to create a new starting scenario for each project.

No-action Scenario. The no-action scenario is essential for any dredging evaluation. It allows the user to estimate net change in risk due to any operation. The no-action evaluation gives the user an indication of the existing, predredging impact of the sediment deposits and the potential risk of the no-action alternative. The no-action scenario is useful in developing comparative risk of multiple alternatives.

The conceptual model for the no-action scenario is shown in Figure 7a. The sources of the contaminants are the sediment and the water column. Interactions between the sources (shown in Figure 7b) include precipitation, dissolution, resuspension, sedimentation, diffusion, adsorption, volatilization, decay, and burial as shown in Figure 4. Potential pathways from the sources to the receptors include ingestion of the sediments or water, direct contact with sediment or water, bioconcentration from the water column, and bio-uptake of organisms. The receptors are humans, piscivorous birds, pelagic fish, forage fish, bottom fish, benthos, and zooplankton.



a. No-action pathway scenario

b. No-action conceptual model for RECOVERY

Figure 7. Conceptual model for the no-action scenario

Figure 8 shows the no-action scenario as implemented in ARAMS/FRAMES. Implementation of the scenario begins with selection of the contaminants of concern and the receptor species. In the generic scenario, the contaminant properties are selected from the FRAMES chemical database, and ecological benchmark data for the chemical effects on receptors are selected from the ERED database. Next, the source module, RECOVERY, is selected to describe the initial conditions in the water column and temporal loadings from nonpoint sources, point sources, and inflow. The source module is linked with the surface water module. The RECOVERY model was selected to model the contaminant interactions between the sediment, water column, and atmosphere, as shown in Figure 7b, because of its flexibility and ease of use. Output from RECOVERY was linked to ecological and human exposure models within FRAMES.

TBP is the ecological exposure model used to assess the effects of exposure to the contaminated sediments and water on biota. The TBP model contains a BSAF database for selecting lipid fractions for the receptor species and BSAF values for the contaminants of concern. TBP then estimates biota body burden in equilibrium with contaminated sediments and water for all of the receptors and contaminants of concern. The TBP model is linked with the ecological effects module to estimate the risks associated with the body burdens.

WEAP is the ecological effects model used to estimate the risk as an ecological hazard quotient or a probability of exceedance of ecological effects criteria. WEAP compares the biota body burden against the effects levels from the ERED database. The model can also make simple comparisons or can estimate statistical violations of criteria over given periods of time. It summarizes and classifies the effects.

MEPAS is the human health exposure model used to calculate the exposure concentrations in media (air, water, soil, and food) that will be exposed to humans (Buck et al. 1995). The concentrations are passed to the MEPAS receptor intake module where the exposure doses are computed. Additionally, the TBP model passes exposure concentrations of aquatic organisms for human

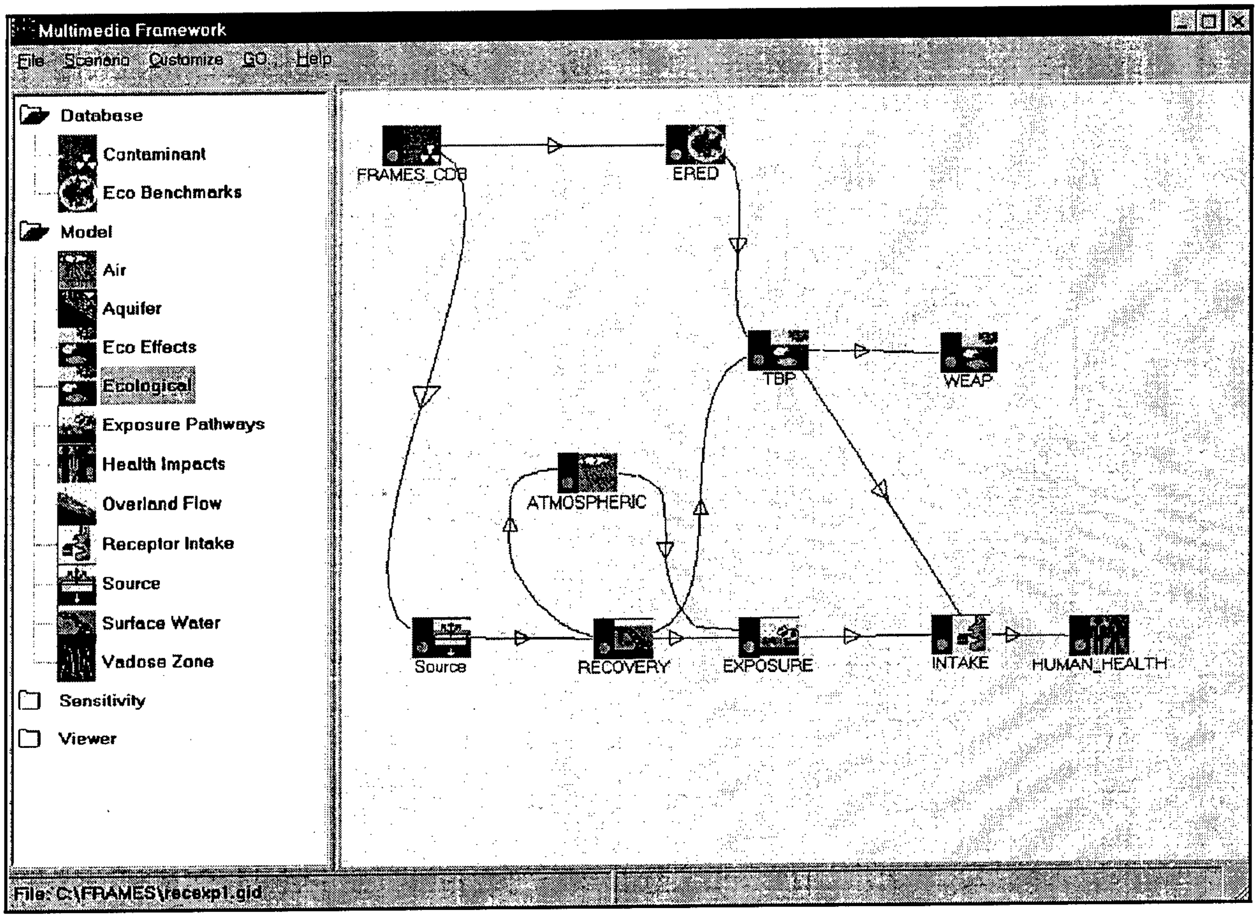


Figure 8. Generic conceptual no-action scenario in ARAMS/FRAMES for both ecological and human health risk assessment

consumption to the receptor intake model. The MEPAS human health impacts module estimates health impacts from inhalation, ingestion, or dermal contacts as either cancer incidences or hazard index as appropriate for the contaminant of concern.

Dredging Scenario. The dredging scenario includes the processes associated with the short-term disturbance caused by the dredging action as well as the processes present in the no-action alternative. Dredging impacts are limited to those associated with the loss of solids and associated contaminants from the dredging operation. The scenario does not include the effects of the physical disturbance or entrainment by the dredge on the organisms. The resuspended material will be transported from the dredging site and dispersed in a plume. The size of the plume where significant increases in contaminant concentrations occur is usually small and may not include the entire depth of the water column. Contaminants from the resuspended material will distribute between the water and solids phases. Solids from the resuspended material plume will settle and deposit on the bottom, changing the contaminant concentration in the surficial sediments. Significant deposition occurs only in the immediate vicinity of the dredge, and the effects of deposition are generally small.

The conceptual model for the dredging scenario is shown in Figure 9. The sources of the contaminants are resuspended material, sediment, and water column. Interactions between the

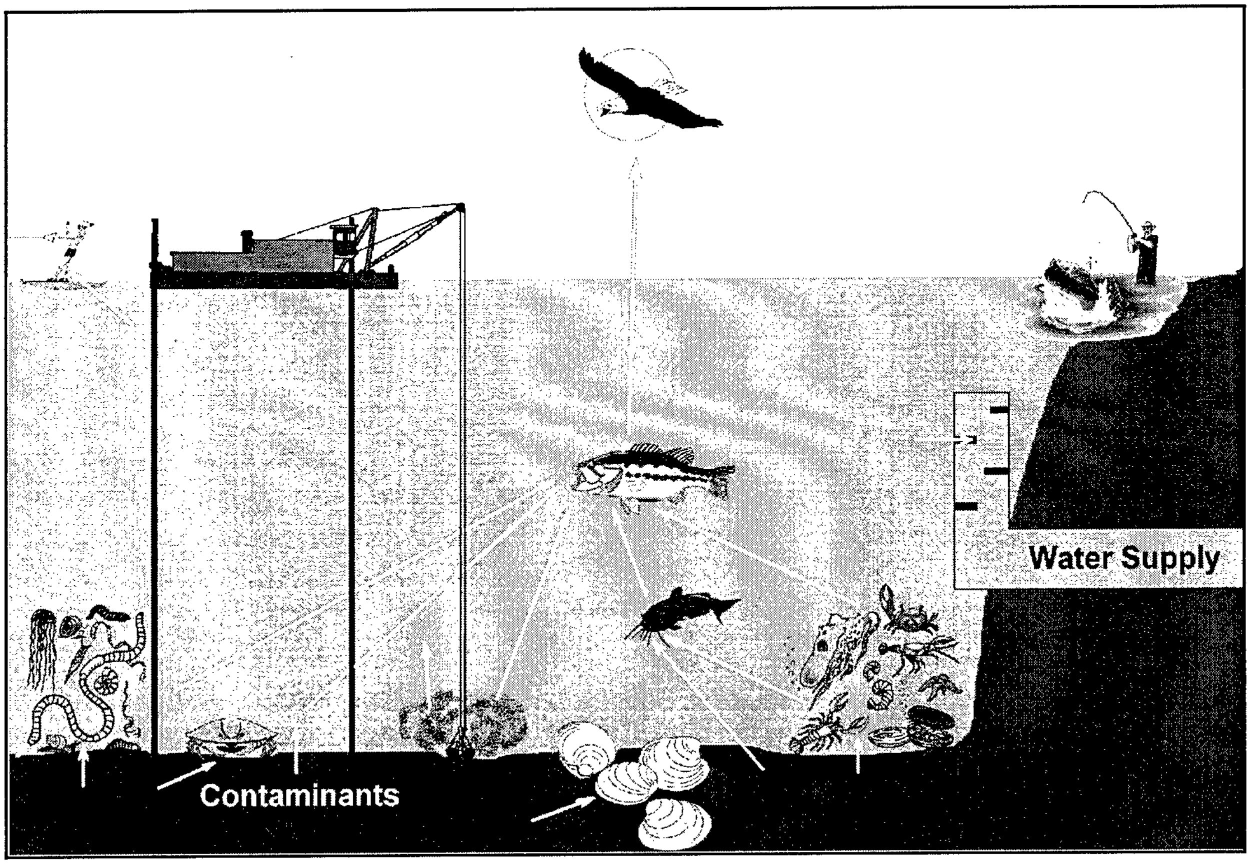


Figure 9. Dredging pathways scenario

sources include precipitation, dissolution, resuspension, sedimentation, diffusion, adsorption, volatilization, decay, and burial as shown in Figure 4. Potential pathways from the sources to the receptors include ingestion of the sediments or water, direct contact with sediment or water, bioconcentration from the water column, and bio-uptake of organisms. The receptors are humans, piscivorous birds, pelagic fish, forage fish, bottom fish, benthos, and zooplankton.

Figure 10 shows the dredging scenario as implemented in ARAMS/FRAMES. Implementation of the scenario begins with selection of the contaminants of concern and the receptor species. In the generic scenario, the contaminant properties are selected from the FRAMES chemical database, and ecological benchmark data for the chemical effects on receptors are selected from the ERED database. Next, the source module, RECOVERY, is selected to describe the initial conditions in the water column and temporal loadings from nonpoint sources, point sources, and inflow. The source module is linked with the surface water modules. The RECOVERY and DREDGE models were selected to model the contaminant interactions between the sediment, water column, and atmosphere because of their flexibility and ease of use. Output from RECOVERY was linked to ecological and human exposure models within FRAMES. Output from DREDGE was linked only to ecological exposure modules because the transient exposure area is typically void of human activities.

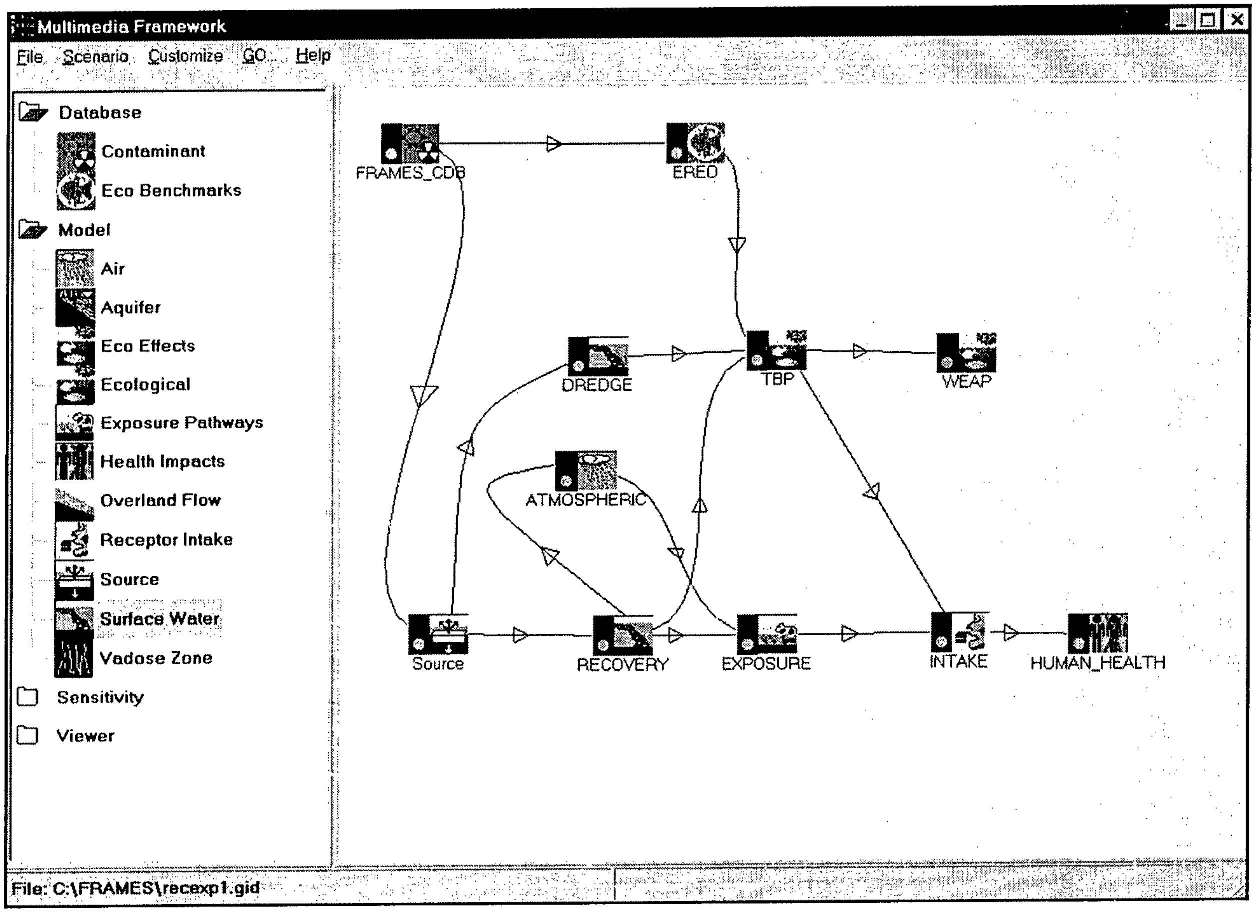


Figure 10. Generic conceptual dredging scenario in ARAMS/FRAMES for both ecological and human health risk assessment

TBP is the ecological exposure model used to assess the effects of exposure to the contaminated sediments and water on biota. The TBP model contains a BSAF database for selecting lipid fractions for the receptor species and BSAF values for the contaminants of concern. TBP then estimates biota body burden in equilibrium with contaminated sediments and water for all of the receptors and contaminants of concern. The TBP model is linked with the ecological effects module to estimate the risks associated with the body burdens.

WEAP is the ecological effects model used to estimate the risk as an ecological hazard quotient, or probability of exceedance of ecological effects criteria. WEAP compares the biota body burden against the effects levels from the ERED database. The model can also make simple comparisons or can estimate statistical violations of criteria over given periods of time. The model summarizes and classifies the effects.

MEPAS is the human health exposure model used to calculate the exposure concentrations in media (air, water, soil, and food) that will be exposed to humans (Buck et al. 1995). The concentrations are passed to the MEPAS receptor intake module where the exposure doses are computed. Additionally, the TBP model passes exposure concentrations of aquatic organisms for human consumption to the receptor intake model. The MEPAS human health impacts module estimates

health impacts from inhalation, ingestion, or dermal contacts as either cancer incidences or hazard index as appropriate for the contaminant of concern.

SUMMARY: The no-action and dredging scenarios are implemented in the Dredging Risk Assessment Modeling Applications (DRAMA). These scenarios are critical components of a comparative ecological and human health risk assessment. The scenarios employ the ADDAMS legacy models and dredging databases to predict contaminant exposures and effects for characterizing risk in a manner consistent with the USACE/USEPA Technical Framework for Evaluating Environmental Effects of Dredged Material Management Alternatives.

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> Deliman, P. N., Ruiz, C. E., and Schroeder, P. R. (2001). "Implementation of Dredging Risk Assessment Modeling Applications for evaluation of the no-action scenario and dredging impacts," *DOER Technical Notes Collection* (ERDC TN-DOER-R2), U.S. Army Engineer Research and Development Center, Vicksburg, MS.
> *www.wes.army.mil/el/dots/doer*

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